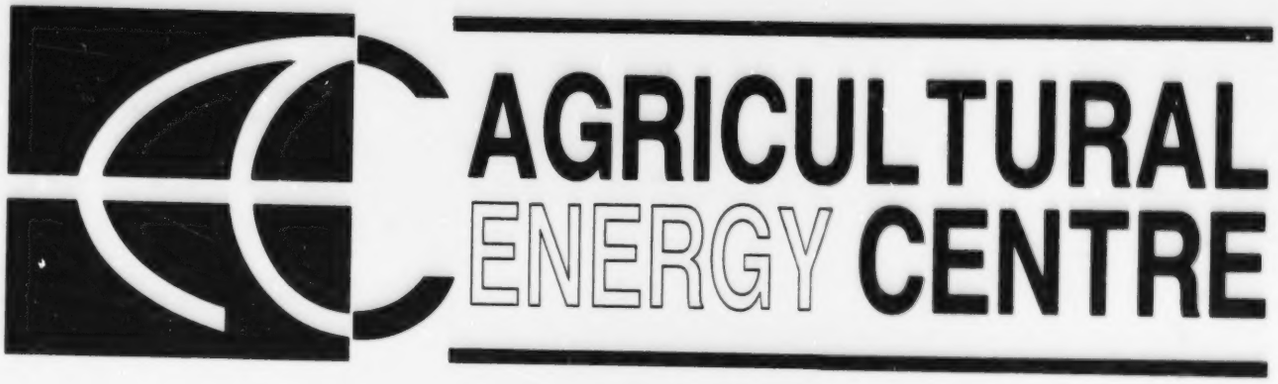
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FAN CYCLING AND REVERSING THE ORIENTATION OF TOBACCO LEAVES IN RACKS IN BULK TOBACCO KILNS

Report No. 88-6116 MAY, 1988

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Report No. 88-6116 MAY, 1988

By:

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ABSTRACT

Effects of cycling the fans of bulk kilns during tobacco curing were investigated. Tests were conducted in bulk kilns equipped with nine racks. Results indicated that fan cycling reduced electrical consumption and improved the average grade value of the tobacco. However, fan cycling increased the curing time and fuel consumption.

In a separate test the benefits of curing tobacco racked with the leaves orientated in the "butts down" position was investigated. The comparative tests were also conducted in the nine rack bulk kilns. Results indicated that the average grade value of tobacco cured in the "butts down" position was significantly less than for tobacco cured in the traditional "butts up" position. Reversing the orientation of tobacco leaves in racks does not appear to affect the curing time and electrical consumption. Results were inconsistent as to whether it conserves fuel.

ACKNOWLEDGEMENTS

The project was a cooperative effort between the Ontario Tobacco Research Advisory Committee and the Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food.

Project funding was provided by the Ontario Ministry of Energy.

We wish to express our thanks to staff of the Agriculture Canada Research Station, Delhi, Ontario, for allowing us to use their facilities and for providing assistance in conducting the testing.

BACKGROUND INFORMATION

Flue-curing tobacco involves an energy intensive crop drying process which requires the evaporation of about 4.5 kilograms of water for every kilogram of cured tobacco. Columbus (1983) estimated that about 31.5 MJ of energy was consumed per kilogram of saleable tobacco to cure the 1981 Ontario tobacco crop. Columbus also reported that bulk kilns equipped with racks were the most fuel energy efficient curing method. The average fuel energy usage of bulk rack kilns in 1981 was 19.2 MJ/kg cf cured tobacco (excludes combustion efficiency of burner). When compared to downdraft and natural convection kilns, bulk rack kilns consume 31% and 42% less fuel energy, respectively.

Bulk rack kilns are equipped with either 3.7 kW or 5.6 kW motors (single or three phase). Ontario Hydro (1983) estimated that the electrical energy consumption of motors operating the fans of bulk rack kilns ranges between 3.4 MJ/kg of cured tobacco for 3.7 kW single phase motors and 4.0 MJ/kg of cured tobacco for 5.6 kW three phase motors. Based on a current electrical cost of $0.055/kWh, electrical energy costs for bulk rack kilns range between 5.2 and 6.1 ¢/kg cf cured tobacco. When compared to downdraft kilns, bulk rack kilns consume up to 5 times more electrical energy.

Assuming that the average fuel energy consumption of a natural gas fired, bulk rack kiln is 22.6 MJ/kg of cured tobacco (includes burner combustion efficiency of

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The mention of manufacturer's trade names is for the purpose of specific product description and does not indicate endorsement or criticism of that product or products not mentioned by the author or the Ontario Ministry of Agriculture and Focd.

85%), the fuel cost, based on $0.18/m^3$ of natural gas, is 10.8¢/kg of cured tobacco. Thus, an electrical cost of 5.2 to 6.1¢/kg of cured tobacco accounts for 32 to 36% of the total energy cost to flue-cure tobacco in bulk rack kilns.

In consideration of the high electrical energy cost component to cure tobacco in bulk rack kilns, methods to reduce electrical consumption warrant investigation.

LITERATURE REVIEW

In the United States, numerous research projects have been conducted on the electrical energy saving potential of cycling the fan of a bulk kiln during curing. The objective of the research was to reduce the electric demand from bulk kilns when electrical distribution systems are operating at peak load.

Watkins (1976) reported that cycling the fans of full-size, bulk rack kilns for 10 minutes off/20 minutes on repeatedly from 15:00 to 21:00 hours during each day of curing reduced electrical energy consumption by 10.9%. The results also indicated that there was no difference in tobacco quality or duration of the cures between fan cycled kilns and continuous fan operated kilns.

Cundiff (1977) reported that cycling the fans of 1/10th scale, bulk rack kilns reduced electrical consumption by 20%. The fans were cycled 15 minutes on/45 minutes off from 12:00 to 21:00 hours each day of the cure. Cundiff did not find any significant difference in the leaf chemistry of tobacco cured in the fan cycled and continuous fan operation kilns. However, the fan cycled cures took about 7 hours longer to cure and consumed about 4% more fuel than the continuous fan operated kilns. Cundiff concluded that the increase in fuel consumption could have been due to differences in combustion efficiencies of the furnace units of the kilns used in the test.

The following year Cundiff (1978) conducted an on-farm demonstration which investigated the effects of cycling the fan of a full-size, bulk rack kiln for 25 minutes off/20 minutes on repeatedly from 12:00 to 17:00 hours during each day of the cure. Results from the field test indicated that the fan cycled kiln required 12% less electrical energy than the continuous fan operated kiln. Cundiff also found that fan cycling had a negligible effect on fuel consumption and that the ratio of reducing sugars to total alkaloids was lower for tobacco cured in the fan cycled kilns as compared to cures in the continuous fan operated kilns.

Maw et al. (1983) conducted an on-farm test which investigated cycling the fan of a bulk rack kiln for 7.5 minutes off/22.5 minutes on repeatedly between 13:00 and 19:00 hours every day during the cures. Results indicated that there was no significant difference in the curing time between fan cycled kilns and continuous fan operated kilns. Electrical savings were about 16%. In addition, a 17% fuel saving was realized. No explanation was given as to why there was a reduction in fuel consumption.

Maw et al. (1986) later examined the effect of fan cycling on different stages of curing. The tests were conducted in bulk kilns equipped with 12 racks. The fans were cycled off 7.5 minutes/on 22.5 minutes repeatedly between 13:00 and 19:00 hours during various stages of curing. Maw et al. concluded that cycling the fan during the leaf and stem drying stages of the cure improved the cured quality of the tobacco.

PROJECT CRITERIA

Based on the research conducted in the United States, fan cycling appears to reduce electrical consumption but it may also affect the length of the cure, fuel consumption and cured tobacco quality. It is not known what effect

fan cycling would have on Ontario grown tobacco. Conducting an on-farm project similar to the U.S. projects was considered too risky. Thus, it was decided that the effects of fan cycling be studied under supervised conditions at the Agriculture Canada Research Station, Delhi, Ontario.

It was decided that various fan cycling treatments ranging from 4.5 minutes off/25.5 minutes on to 12 minutes off/18 minutes on would be investigated. Instead of cycling the fans for part of the day during each day of curing, the fans would be cycled during the entire day for each day of curing.

This location provided an ideal opportunity to investigate another idea that might have energy saving potential. It was thought that reversing the orientation of leaves in racks in bulk kilns could reduce air resistance and decrease the length of time required to dry the tobacco. Instead of packing the leaves in the racks with the "butts up", the leaves would be reversed or in other words racks would be packed with leaves in "butts down" position. This could possibly result in: a more uniform cure; decrease curing time; and reduce fuel and electrical consumption. There had been no research to suggest this to be true, however, it was deemed worthy of investigation.

OBJECTIVES

1) Determine the effects of various fan cycling treatments on curing energy consumption and cured tobacco quality.
2) Determine the effects on curing, energy consumption and cured tobacco quality by reversing the orientation of tobacco leaves packed in racks.

METHOD

Testing Facilities

The projects were conducted at the Agriculture Canada Research Station, Delhi, Ontario. Six "mini-bulk kilns" (mini-kilns) at the station were used (see Figure 1).

The mini-kilns are basically of the same configuration as full size bulk kilns, however with one exception, the loading capacity of each mini-kiln is 9 racks instead of the usual 150 to 180 racks for full size bulk kilns.

Each mini-kiln is equipped with an indirect-fired, natural gas burner rated at about 100 MJ/h. The fuel input rate of each burner was adjusted to about 75 MJ/h for the test series. In addition, the combustion efficiency of each burner was adjusted so that all the burners were operating at similar efficiencies.

Each mini-kiln is equipped with a squirrel cage fan 250 mm in diameter. Each fan was set at 800 rpm to provide 470 L of air per second at 185 Pa. Each fan is belt driven by a 0.75 kW motor.

All of the mini-kilns are insulated in the same locations. A 50 mm thickness of expanded polystyrene insulation lines the ceilings, sidewalls and partitions between the curing compartments and the burner/fan compartments. The doors and floors of the mini-kilns are insulated with 38 mm thick expanded polystyrene.

Fan Cycling and Reversed Leaf

Four of the six mini-kilns were selected for fan cycling. An "Intermatic Time Controls, model C8865" time clock was installed in the electrical circuit powering the fan motor of each kiln. The electrical circuit between the thermostat and the gas solenoid valve was also wired to the time clock to prevent the burner from operating when the fan was off.

The cycle duration of the time clocks is 1 hour. Metal trippers on the time clocks divide the hour into segments of 30 seconds. The cycle duration of each time

clock was set at 30 minutes. Thus, the cycle was repeated every 30 minutes for the entire cure. Fan cycle treatments used in the four mini-kilns to cure five primings of tobacco were as follows:

Fan Cycle Treatments For Priming 1 (P1)

kiln #1: 12 minutes off/18 minutes on (40% off time)
#2: 9 minutes off/21 minutes on (30% off time)
#3: 6 minutes off/24 minutes on (20% off time)
#4: 4.5 minutes off/25.5 minutes on (15% off time)

Fan Cycle Treatments For Primings 2, 3, 4 and 5 (P2, P3, P4 and P5)

kiln #1: 9 minutes off/21 minutes on (30% off time)
#2: 7.5 minutes off/22.5 minutes on (25% off time)
#3: 6 minutes off/24 minutes on (20% off time)
#4: 4.5 minutes off/25.5 minutes on (15% off time)

The fifth mini-kiln was used for reversing the orientation of the tobacco leaves from "butts up" to "butts down" in the racks (referred to as reversed leaf kiln). Five primings of tobacco were cured in the reversed leaf kiln.

The sixth mini-kiln was used as a check kiln. The fan was operated continuously and the orientation of the tobacco leaves were "butts up" in the racks. Five primings of tobacco were cured in the check kiln.

Curing Schedule

For each priming the kilns were loaded simultaneously with tobacco from the same field. Curing began immediately after loading. The cureman used his judgement based on experience in selecting the curing schedule for each cure in all six kilns.

MONITORING

A "Kaye-Digi III" datalogger and type T thermocouples were used to record: dry-bulb and wet-bulb temperatures

in the lower plenum of each mini-kiln; dry-bulb temperatures in the upper plenum of each mini-kiln; and the ambient air temperature.

Each mini-kiln was equipped with individual natural gas and kilowatt-hour meters. The meters were read twice per day during curing.

Leaf samples were collected during loading and after casing from each cure in the mini-kilns. The samples were used to determine the initial and final moisture contents of the tobacco. The method used to determine moisture content is described in appendix 1. The method assumes that all weight loss during curing is moisture loss and does not indicate any loss of dry matter which occurrs when volatile constituents are evaporated. (Suggs and Mohapatra (1986) reported that the maximum amount of error is 3% when assuming total weight loss is a result of moisture removal.)

Cured subsamples were collected at random from each mini-kiln. A chemical analysis was done to determine percentages of total alkaloids and reducing sugars. After the completion of curing the tobacco was graded according to the Ontario flue-cured tobacco grading system adopted in 1987.

RESULTS AND EVALUATION

i) FAN CYCLING

Moisture Content and Water Removed

Table 1 shows the initial and final moisture contents of tobacco cured in the four fan cycled kilns and the continuous fan operated kiln.

It is evident that the initial moisture content of the tobacco decreased with ascending stalk position tobacco. The moisture content ranged from an average of 80% (w.b.) for the lower priming (P2) to an average of 73% (w.b.) for the upper priming (P5). Unfortunately, no moisture contents were recorded for the first priming (P1).

The variability in final moisture contents of similar tobacco primings can be attributed to the casing method used. Each kiln of tobacco was cased separately which made it extremely difficult to condition the tobacco from each priming to identical final moisture contents. The final moisture content for the different primings varied between 12.4 and 20.4% (w.b.).

The results also show that the amount of water removed from similar primings varied. This can be attributed to differences in the amount of green tobacco loaded into each kiln.

Duration of Cures

Table 2 shows the length of time required to cure the different tobacco primings in the fan cycled kilns and continuous fan operated kiln. Generally, tobacco in the fan cycled kilns took longer to cure than in the continuous fan operated kiln.

Results from P1 cures indicate that cycling the fan off for 40% and 20% of the time extended the length of the cure by 44 and 24 hours, respectively, as compared to the continuous fan operated kiln. Whereas cycling the fan off for 30% and 15% of the time did not extend the length of the cure as compared to the continuous fan operated kiln.

Results from P2, P3 and P4 cures indicate that the fan cycled kilns usually required longer to cure than the continuous fan operated kiln. It also appears that the longer the fan was off the longer the cure time.

Results from P5 cures indicate that cycling the fan did not significantly affect the cure time. However, it should be noted that the curing schedule for P5 cures was slightly different than that used for the other cures.

During P5 cures the fan cycled kilns were cured at the same dry-bulb temperatures as the continuous fan operated kiln (example shown in Figure 2). This was not the case during the majority of P1 to P4 cures when the dry-bulb temperatures were advanced at a slower rate after yellowing in the fan cycled kilns than in the continuous fan operated kiln (example shown in Figure 3). During the P1 to P4 cures, increasing the dry-bulb temperatures of the fan cycled kilns at the same rate as in the continuous fan operated kiln would have resulted in scalding the tobacco because the majority of fan cycled kilns were at a much higher relative humidity than the continuous fan operated kiln. The opposite occurred during P5 cures. The fan cycled kilns were at a relative humidity similar to that of the continuous fan operated kiln which allowed the dry-bulb temperature to be increased at the same rate in all kilns without scalding the tobacco.

Thus, during the majority of P1 to P4 cures, advancing the dry-bulb temperatures in the fan cycled kilns at a slower rate than in the continuous fan operated kiln resulted in increased cure times. Similar cure times resulted during P5 cures when the dry-bulb temperatures in the fan cycled kilns were advanced at the same rate as in the continuous fan operated kilns.

Electrical Consumption Per Cure

Table 3 shows the amount of electricity consumed per cure in the fan cycled kilns and the continuous fan operated kilns. The fan cycled kilns consumed less electricity per cure, however, since the majority of cures in the fan cycled kilns required longer to cure, the percent of electricity saved was less than the percent off time during cycling.

Results from the five primings cured in the fan cycled kilns indicate that the electrical savings averaged 11.5% for the 15% off kiln, 14.4% for the 20% off kiln and 23.0%

for the 30% off kiln. The other kiln which was fan cycled off for 40% of the time during the P1 cure and for 25% of the time during the P2 to P5 cures resulted in electrical savings of 28.0% for the P1 cure and averaged 17.3% for P2 to P5 cures.

Fuel Consumption

Table 4 shows the amount of fuel consumed per unit of water removed from tobacco in the fan cycled kilns and the continuous fan operated kilns. The specific fuel energy consumption of the P1 cures could not be calculated because samples of the initial moisture contents of the tobacco were not taken.

The majority of cures in the fan cycled kilns required more fuel energy than cures in the continuous fan operated kiln. As compared to cures in the continuous fan operated kiln and excluding P1 cures, P2 to P5 cures required an average of 13.8% more fuel in the 30% off kiln, 10.6% more fuel in the 25% off kiln, 7.4% more fuel in the 20% off kiln and 5.4% more fuel in the 15% off kiln.

The results also indicate that during similar cures there does not appear to be any relationship between fuel consumption and length of fan cycling. Results from P2 cures indicate that more fuel was consumed by the kiln cycled off for 15% of the time than the kiln cycled off for 30% of the time. The reverse occurred for P3 cures. Whereas for P4 and P5 cures the most fuel was consumed by kilns cycled off for 25% and 20% of the time, respectively.

Cumulative Gas Usage

Figure 4 illustrates the cumulative gas use of P1 cures versus elapsed curing time. The rate of gas use was similar in kilns that were fan cycled off for 20%, 30% and 40% of the time as compared to the continuous fan operated kiln (labelled as chk. in graph). It appears

that the additional fuel consumptions of kilns that were fan cycled off for 40% and 20% of the time were a result of the additional time required to complete the cure.

There was a different reason for the significantly greater fuel consumption for the kiln that was fan cycled off for 15% of the time. As compared to the continuous fan operated kiln, the kiln that was fan cycled off for 15% of the time consumed the same rate of gas for the first 90 hours of curing. After 90 hours of curing the rate of gas consumption increased significantly. Figure 5 shows that from 90 to 160 hours of curing the relative humidity in the fan cycled kiln was significantly less than in the continuous fan operated kiln. This was a result of increasing the air exchange rate which explains why the fan cycled kiln consumed significantly more fuel than the continuous fan operated kiln.

It had been expected that the fan cycled kilns would have a higher relative humidity than the continuous fan operated kilns because very little air was exchanged when the fan is off. This was offset in some cures such as the 15% off kiln in the P1 cure by increasing the damper opening which reduced the relative humidity level below that of the continuous fan operated kiln and resulted in greater fuel consumption.

Figures 6, 7, 8 and 9 illustrate the cumulative gas use versus elapsed curing time of other cures in the fan cycled kilns and continuous fan operated kiln. For the majority of cures in the fan cycled kilns, the greater gas consumption resulted from either a longer cure time or lower relative humidity than in the continuous fan operated kiln.

Tobacco Grades

Tables 5 to 9 show the grade composition of tobacco cured in the fan cycled kilns and continuous fan operated kiln. It should be noted that the majority of tobacco cured in the fan cycled kilns had a higher grade value than tobacco cured in the continuous fan operated kiln.

The grade value for the 5 primings of tobacco cured in the continuous fan operated kiln averaged $3.49/kg. The average grade value of the 5 primings of tobacco cured in the fan cycled kilns was $3.60/kg for the 30% off kiln, $3.64 for the 20% off kiln and $3.52 for the 15% off kiln.

Leaf Chemistry

Table 10 shows the percent total alkaloids and percent reducing sugars of tobacco cured in the fan cycled kilns and the continuous fan operated kiln. The percent total alkaloids was not affected by fan cycling, however, the percent reducing sugars for the P3, P4 and P5 cures in the fan cycled kilns was significantly lower than for similar cures in the continuous fan operated kiln.

ii) REVERSED LEAF IN RACKS

Moisture Content and Water Removed

Table 11 shows the initial and final moisture contents, cased tobacco mass and the amount of water removed for cures in the reversed leaf kiln and the check kiln.

It should be noted that loading racks with leaves positioned in the opposite direction made it very difficult to judge when the racks were sufficiently filled. For the tests it was necessary to weigh the racks to determine when they were full.

Length of Time To Cure

Table 12 shows the length of time to cure the different

tobacco primings in the reversed leaf kiln and the check kiln. The P1 cure in the reversed leaf kiln required 28 h less time to cure than the comparable cure in the check kiln. The other cures in the reversed leaf kiln required only slightly shorter times to cure than cures in the check kiln.

Electrical Consumption

Table 13 shows the electrical consumptions of cures in the reversed leaf kiln and the check kiln. Since electrical consumption is directly related to the length of the cure, the P1 cure in the reversed leaf kiln required 13% less electrical energy than the cure in the check kiln. The other cures in the reversed leaf kiln required the same or only slightly less electrical energy than cures in the check kiln.

Fuel Consumption

Table 14 shows the amounts of fuel energy consumed to remove water from tobacco cured in the reversed leaf kiln and the check kiln. The fuel energy consumption of the P1 cures could not be calculated because samples of the initial moisture contents of the tobacco were not taken. Results from P3 and P5 cures indicate that the fuel energy consumptions for cures in the reversed leaf kiln were 21.7% and 8.9% less than for comparable cures in the check kiln. Whereas for P2 and P4 cures the fuel energy consumptions for cures in the reversed leaf kiln were 4.7% and 24.7% greater than for comparable cures in the check kiln.

Tobacco Grades

Tables 15 to 19 show the grade composition of cures in the reversed leaf kiln and the check kiln. The average grade value of cures in the reversed leaf kiln was $3.18 per kilogram as compared to $3.49 per kilogram for cures in the check kiln. Thus, reversing the orientation of

the leaves in the racks reduced the grade value of the tobacco.

Leaf Chemistry

Table 20 shows the % total alkaloids and % reducing sugars of tobacco cured in the reversed leaf kiln and the check kiln. The results indicate that there does not appear to be any significant difference in leaf chemistry between comparable cures in the reversed leaf kiln and check kiln.

CONCLUSIONS

FAN CYCLING

1) Fan cycling reduced electrical consumption and increased the cure time for the majority of cures. It appears that both are dependant upon: duration of off time during cycling; rate of dry-bulb temperature advance; and amount of air exchange.
2) Fan cycling increased fuel consumption. This was a result of either a longer cure time or lower relative humidity levels during curing.
3) Overall, fan cycling to a maximum of 30% off time appears to improve the grade value of tobacco.

REVERSED LEAF IN RACKS

1) Curing tobacco in the "butts down" position did not reduce electrical consumption or cure time. Results were inconsistent as to whether it conserves fuel.
2) Overall, tobacco cured in the "butts down" position in racks had a significantly lower grade value than tobacco cured in the "butts up" position in racks.

RECOMMENDATIONS

1) The fan cycling project should be repeated again in 1988 to validate 1987 results. The curing schedule

should be more closely monitored to reduce over-ventilation and excessive relative humidity suppression.

2) Curing tobacco in the "butts down" position in racks should not be recommended to tobacco growers and no further testing is proposed for 1988.

LITERATURE CITED

Columbus, M. J. 1983. Tobacco curing energy needs in Ontario an industry survey - 1981. Energy Management Report. OMAF Agricultural Energy Centre, Toronto.

Cundiff, T. S. 1977. Methods for reducing tobacco bulk curing impact on peak demand. ASAE Paper No. 77-3047. Am. Soc. of Agric. Eng., St. Joseph, Michigan.

Cundiff, J. S. 1978. Fan cycling and energy consumption in bulk tobacco curing. Department of Ag. Eng. Research Report 288. University of Georgia, Georgia.

Maw, B. W., P. E. Summer, M. G. Stephenson 1985. Radio controlled fan cycling during bulk tobacco curing. ASAE Paper No. 83-3537. Am. Soc. of Agric. Eng., St. Joseph, Michigan.

Ontario Hydro 1983. Single or three phase power? It pays to check with Hydro's Area Office. Energy Management On The Farm Technical Bulletin. Ontario Hydro Energy Conservation and Utilization Division, Toronto.

Suggs, C. W. and S. C. Mohapatra 1986. Dry matter and moisture loss of bright leaf tobacco during curing. Paper No. 86-3055. Am. Soc. of Agric. Eng. St. Joseph MI. 49085.

Watkins, R. W. 1976. Farm scale testing of intermittent fan operation in bulk curing tobacco. Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, North Carolina.

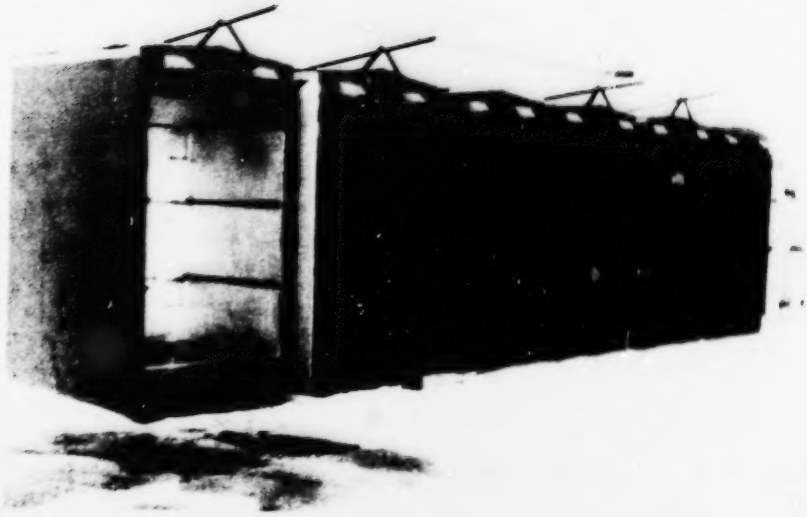

Figure 1: Mini-kilns used for tobacco curing.

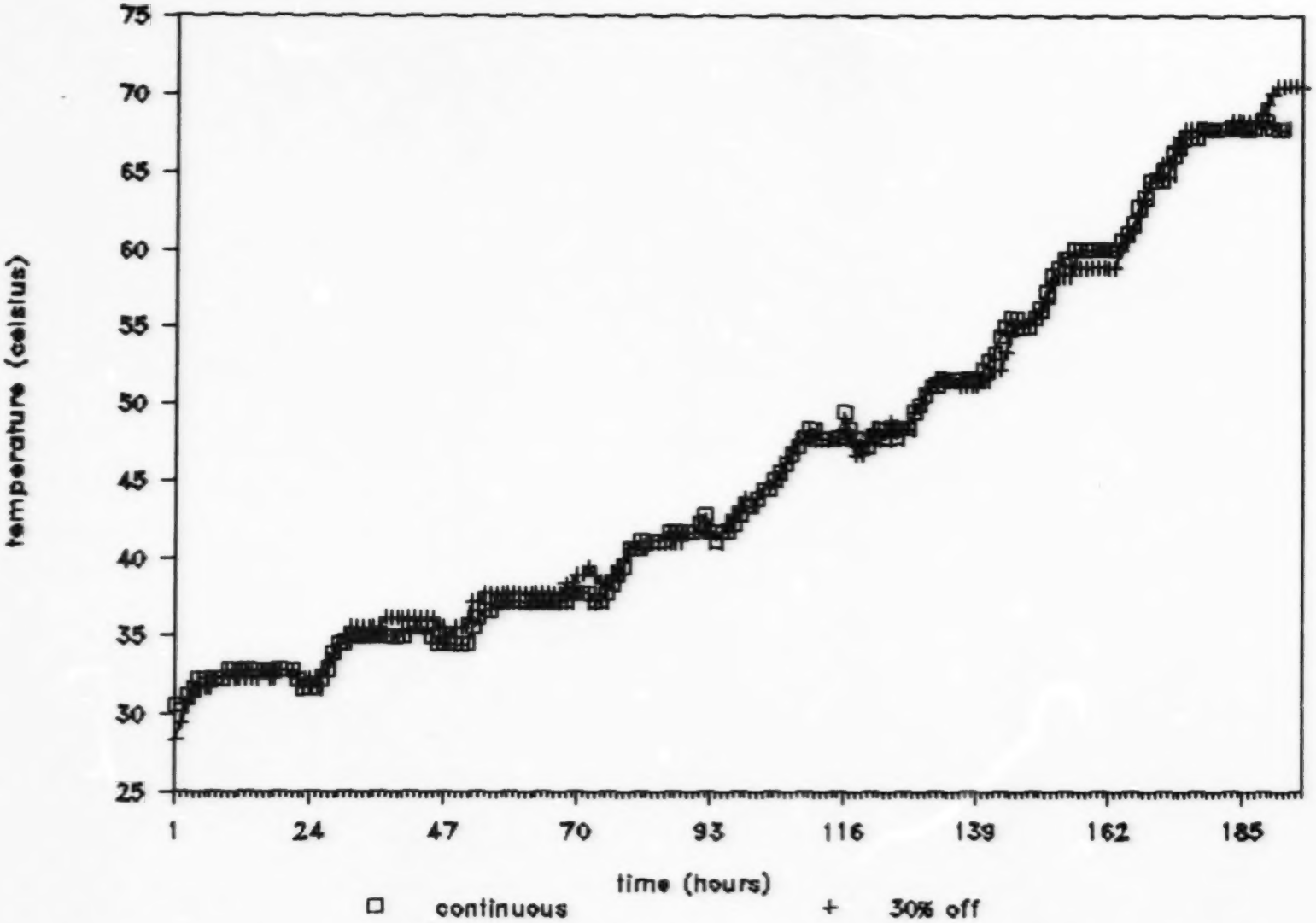

Figure 2: Dry-bulb temperature history during P5 cures in the continuous fan operated kiln and kiln cycled off for 30% of the time.

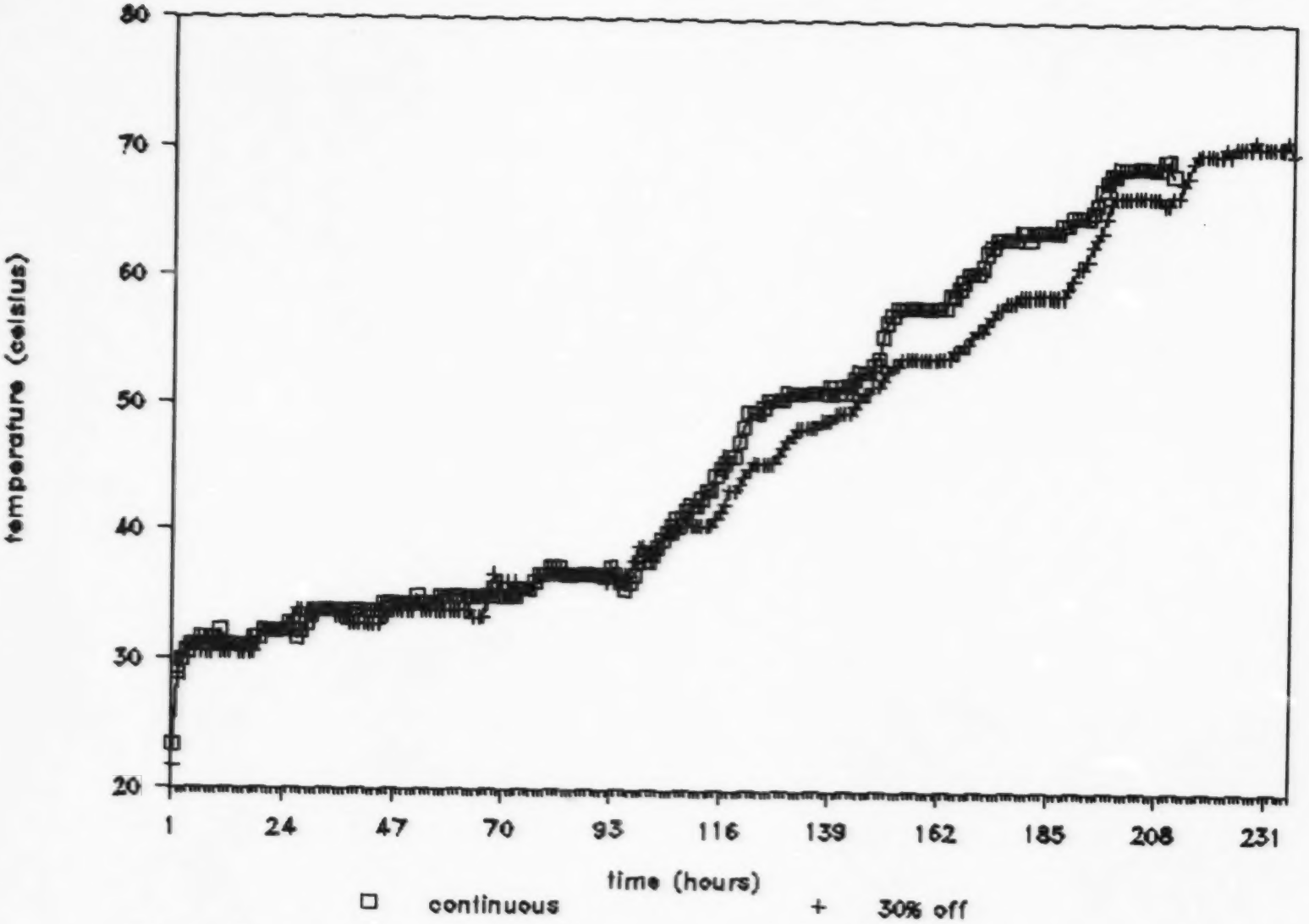

Figure 3: Dry-bulb temperature history during P4 cures in the continuous fan operated kiln and kiln cycled off for 30% of the time.

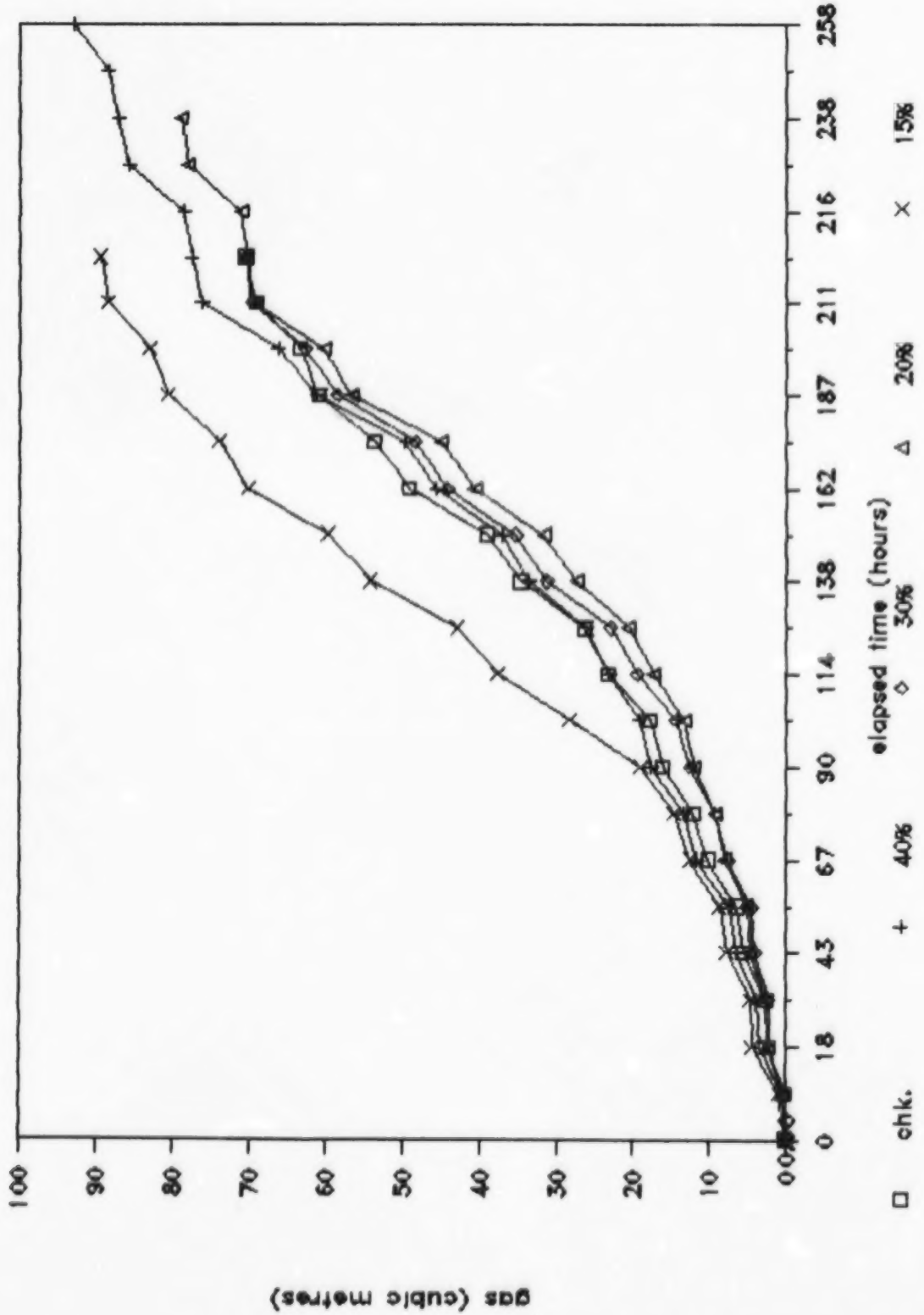

Figure 4: Gas consumption history of P1 cures.

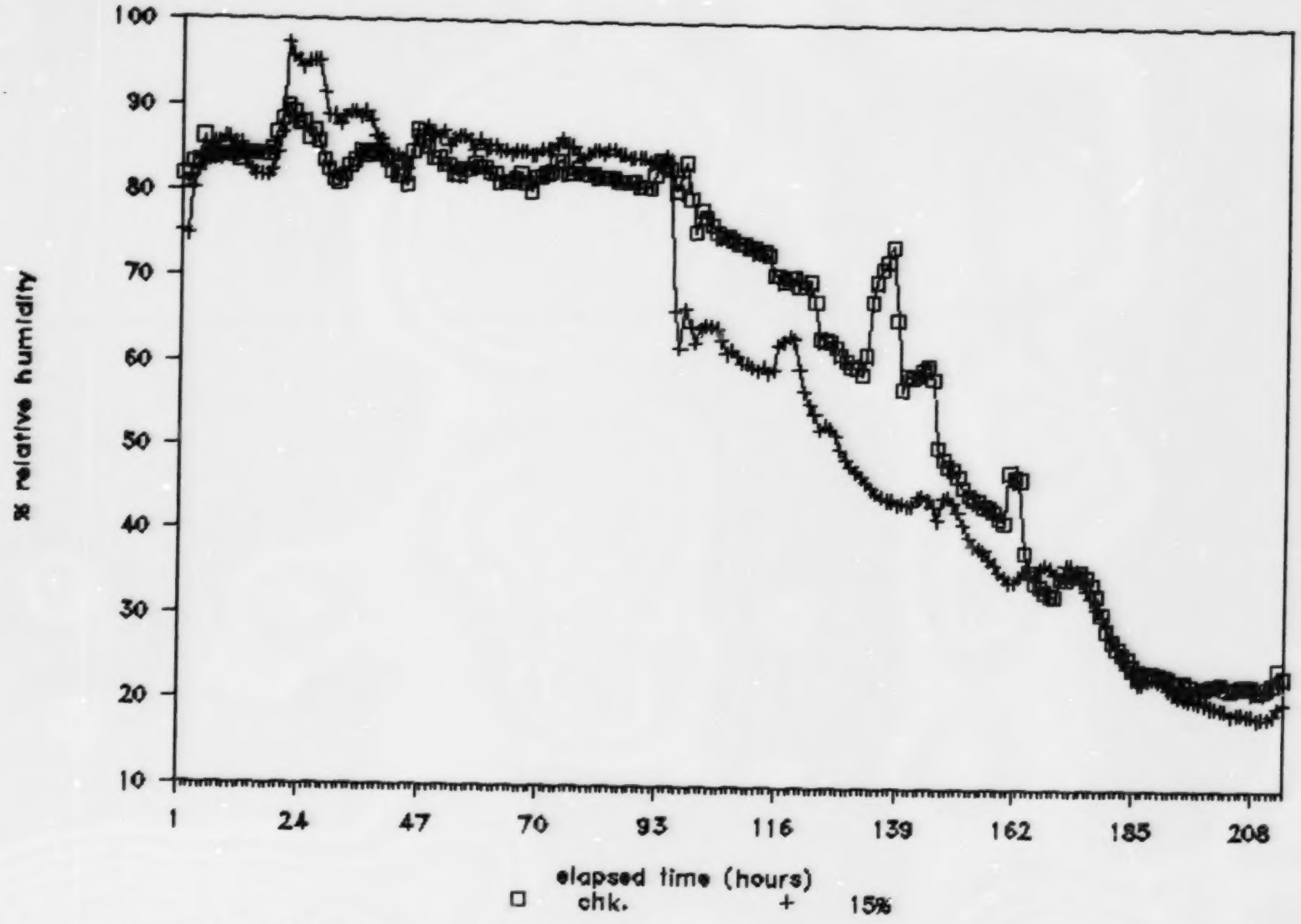

Figure 5: Relative humidity history during P1 cures in the continuous fan operated kiln (ch k.) and kiln cycled off for 15% of the time (15%).

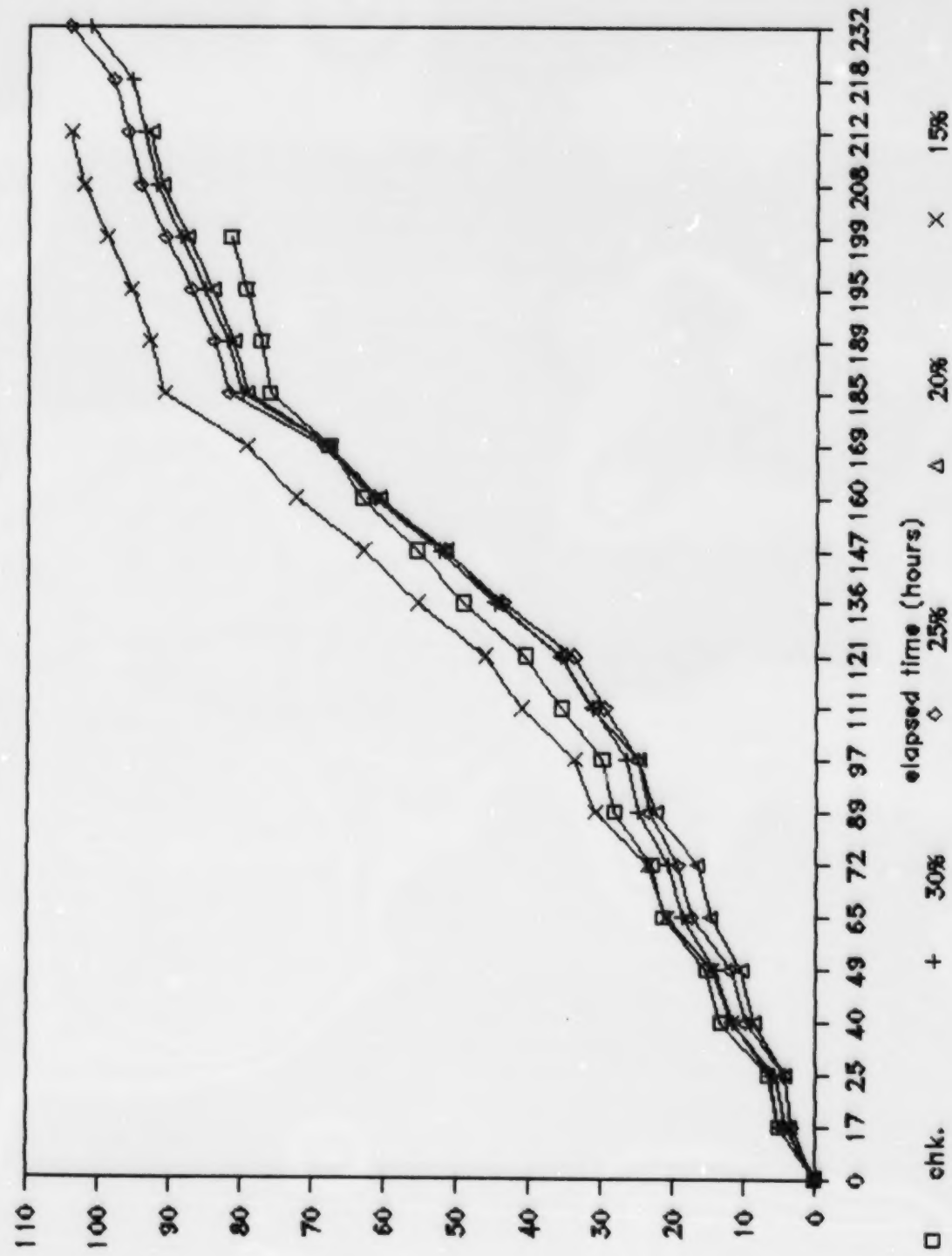

Figure 6: Gas consumption history of P2 cures.

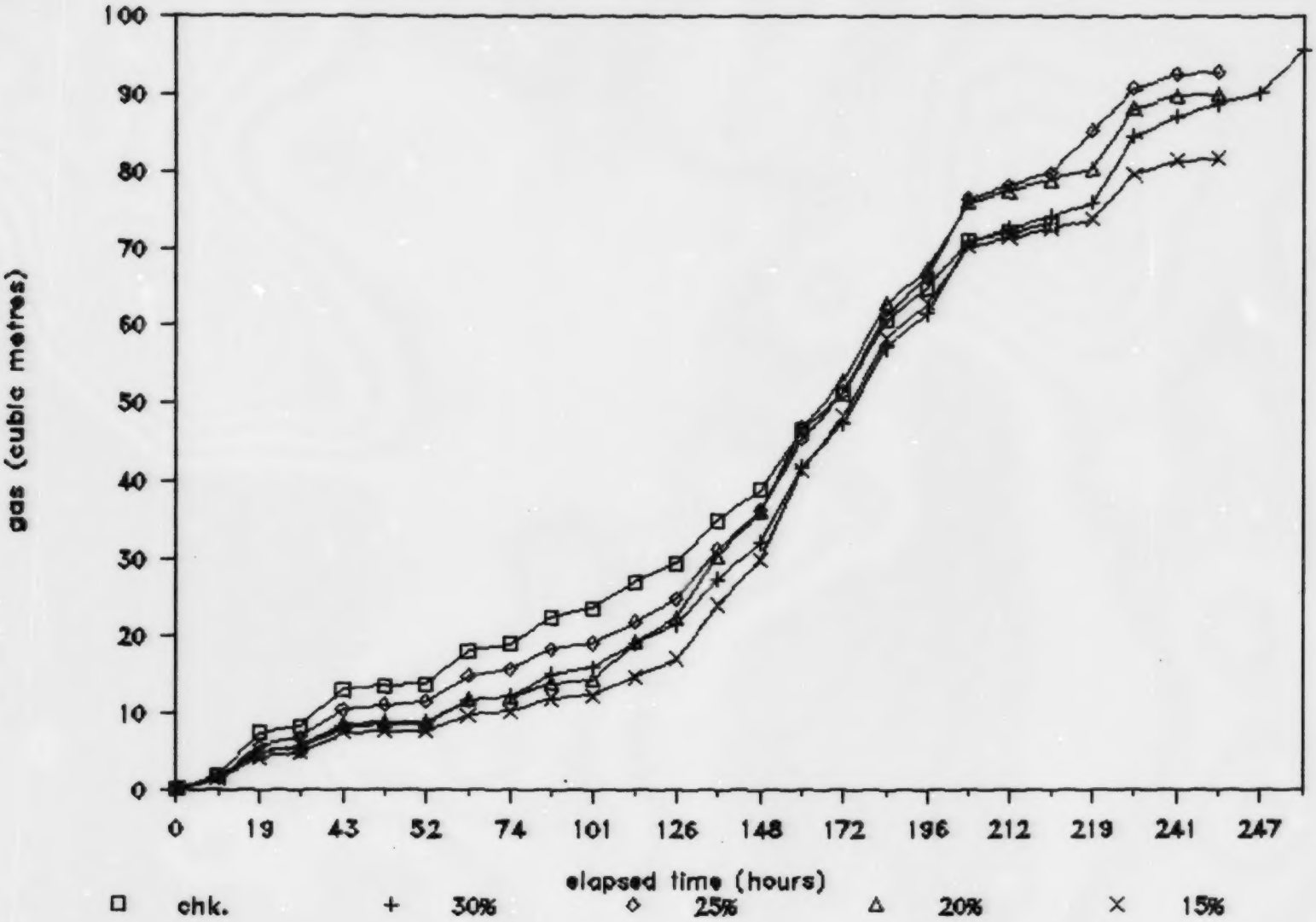

Figure 7: Gas consumption history of P3 cures.

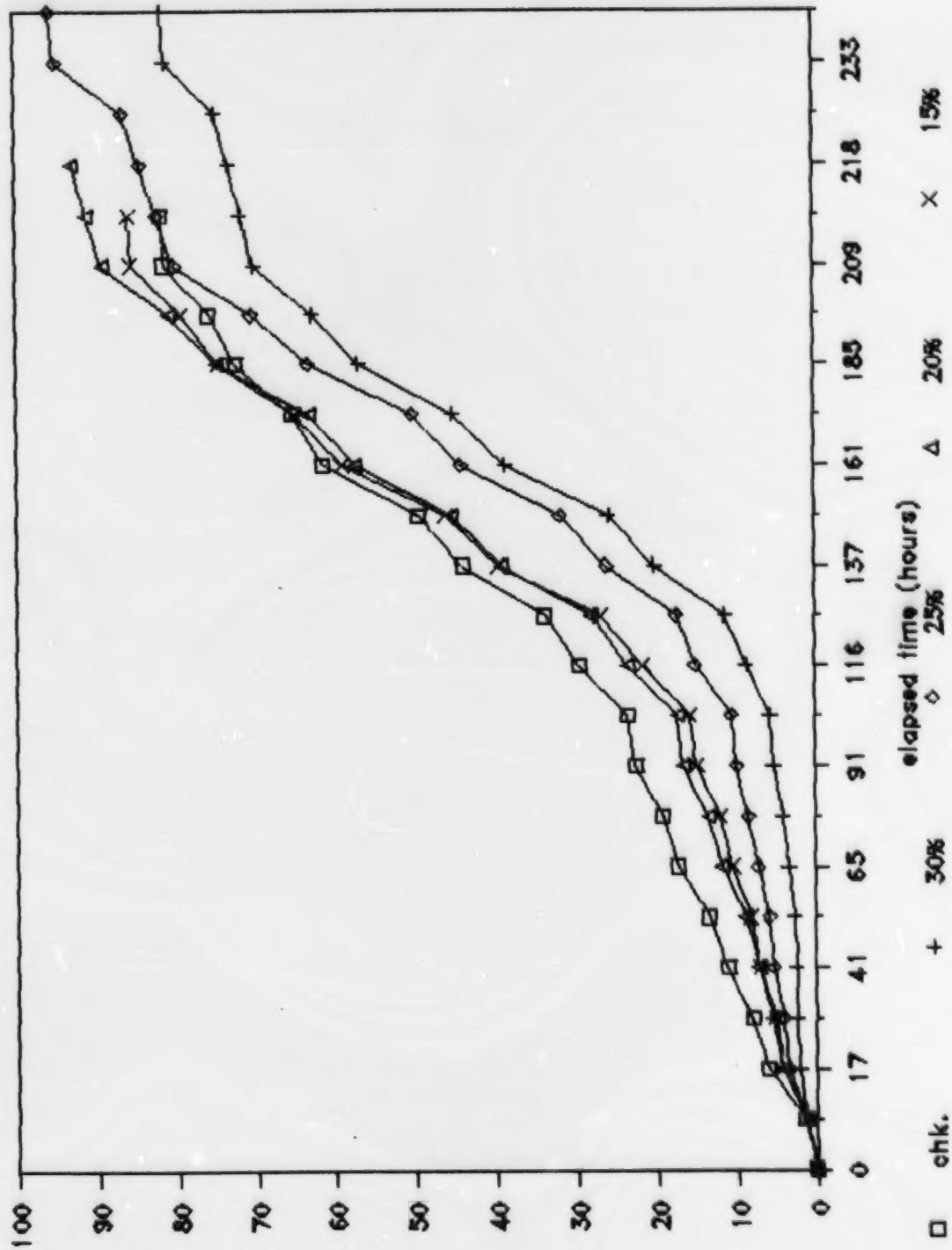

Figure 8: Gas consumption history of P4 cures.

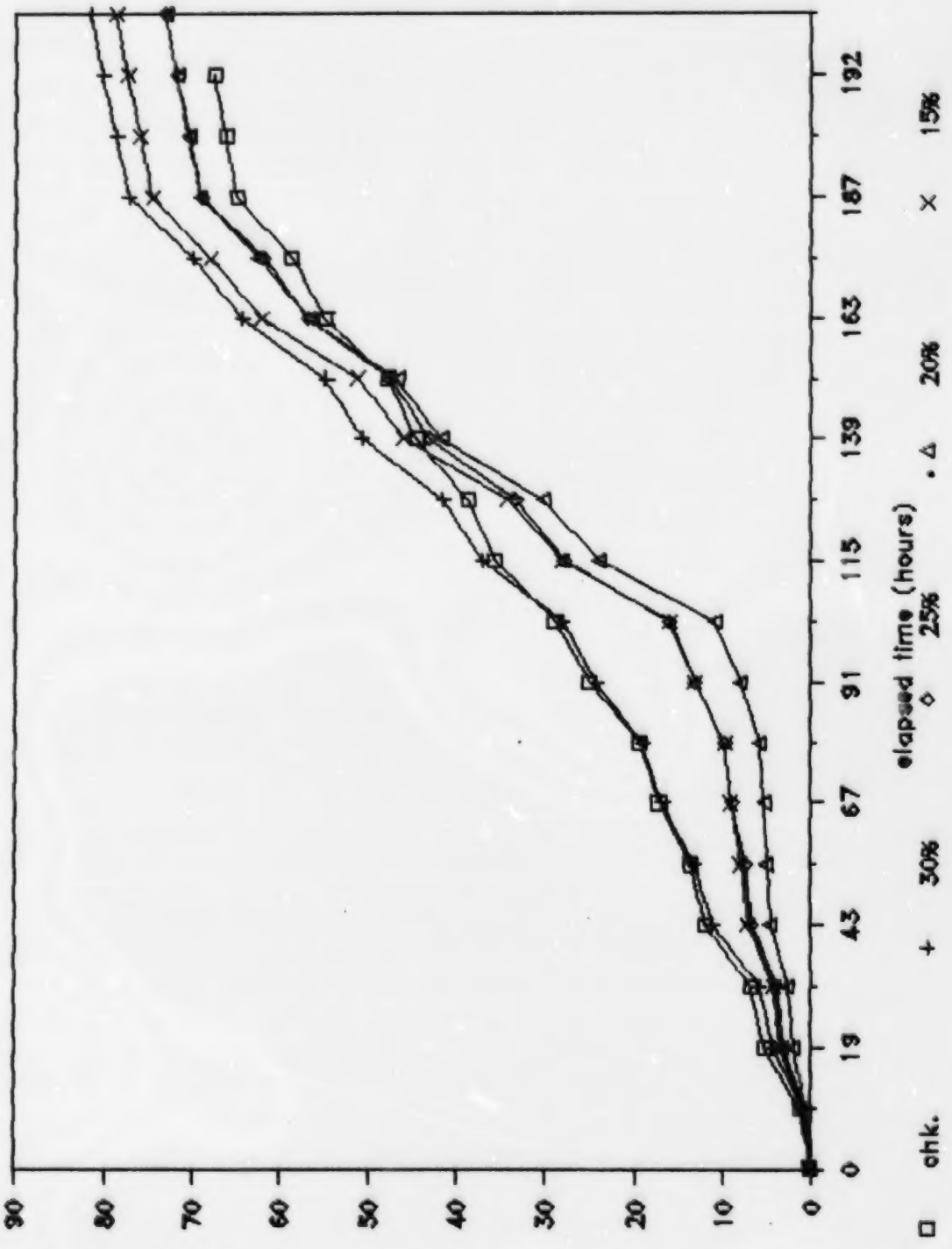

Figure 9: Gas consumption history of P5 cures.

Table 1: Moisture content and water removed from cures in the fan cycled kilns and continuous fan operated kiln.

Fan Treatment (% of 30 min.)	Priming	Moisture Content (w.b.) initial (%)	final (%)	Cased Tobacco Mass (kg)	Water Removed (kg)
continuous	P1	--	17.6	61.2	--
40% off	P1	--	17.0	60.3	--
30% off	P1	--	16.7	62.1	--
20% off	P1	--	17.7	65.3	--
15% off	P1	--	17.9	68.9	--
continuous	P2	79.2	13.3	75.3	248.6
30% off	P2	80.5	15.2	82.6	289.2
25% off	P2	82.0	13.1	83.0	328.6
20% off	P2	78.5	12.8	83.0	264.3
15% off	P2	80.6	14.2	74.4	265.2
continuous	P3	76.5	16.6	88.5	240.3
30% off	P3	79.5	15.7	74.4	243.2
25% off	P3	79.5	12.4	78.9	268.0
20% off	P3	81.5	15.4	81.6	304.1
15% off	P3	80.9	15.0	72.6	261.4
continuous	P4	73.7	15.2	113.9	270.7
30% off	P4	75.0	18.1	100.2	246.2
25% off	P4	75.1	17.6	100.7	250.3
20% off	P4	75.4	14.9	108.4	282.7
15% off	P4	75.3	16.2	115.2	294.3
continuous	P5	72.6	20.1	116.6	246.8
30% off	P5	73.1	18.4	122.9	272.5
25% off	P5	73.3	18.6	112.9	252.3
20% off	P5	71.6	20.4	113.4	227.6
15% off	P5	74.1	17.8	118.8	279.4

Table 2: Summary of curing times for cures in the fan cycled kilns and continuous fan operated kiln

Fan Treatment (% of 30 min.)	Priming	Cure Time (h)	Cure Time (h diff.)*	Cure Time (% diff)**
continuous	P1	214.0	--	--
40% off	P1	258.0	+44.0	20.6
30% off	P1	214.0	0.0	0.0
20% off	P1	238.0	+24.0	11.2
15% off	P1	214.0	0.0	0.0
continuous	P2	199.0	--	--
30% off	P2	232.0	+33.0	16.6
25% off	P2	232.0	+33.0	16.6
20% off	P2	212.0	+13.0	6.5
15% off	P2	212.0	+13.0	6.5
continuous	P3	216.0	--	--
30% off	P3	258.0	+42.0	19.4
25% off	P3	242.0	+26.0	12.0
20% off	P3	242.0	+26.0	12.0
15% off	P3	242.0	+26.0	12.0
continuous	P4	209.5	--	--
30% off	P4	234.0	+24.5	11.7
25% off	P4	234.0	+24.5	11.7
20%	P4	217.5	+8.0	3.8
15%	P4	209.5	0.0	0.0
continuous	P5	192.0	--	--
30% off	P5	195.0	+3.0	1.6
25% off	P5	195.0	+3.0	1.6
20% off	P5	195.0	+3.0	1.6
15% off	P5	195.0	+3.0	1.6

* difference in cure time between fan cycled kiln and continuous fan operated kiln

**percent difference in cure time between fan cycled kiln and continuous fan operated kiln.

Table 3: Electrical consumption for cures in the fan cycled kilns and continuous fan operated kiln

Fan Treatment (% of 30 min.)	Priming	Electrical Consumption Per Cure (kWh)	(% diff.)*
continuous	P1	107	--
40% off	P1	77	-28.0
30% off	P1	75	-29.9
20% off	P1	95	-11.2
15% off	P1	91	-15.0
continuous	P2	99	--
30% off	P2	81	-18.2
25% off	P2	87	-12.1
20% off	P2	84	-15.2
15% off	P2	90	-9.1
continuous	P3	108	--
30% off	P3	90	-16.7
25% off	P3	90	-16.7
20% off	P3	96	-11.1
15% off	P3	102	-5.6
continuous	P4	104	--
30% off	P4	82	-21.2
25% off	P4	87	-16.3
20% off	P4	87	-16.3
15% off	P4	89	-14.4
continuous	P5	96	--
30% off	P5	68	-29.2
25% off	P5	73	-24.0
20% off	P5	78	-18.8
15% off	P5	83	-13.5

* percent difference in electrical consumption between fan cycled kiln and continuous fan operated kiln

Table 4: Fuel energy consumption for cures in the fan cycled kilns and continuous fan operated kiln.

Fan Treatment (% of 30 min.)	Priming	Water Removed (kg)	Gas (m^3)	Fuel Energy (MJ)*	Fuel Energy Consumption (MJ/kg water)	(% diff)**
continuous	P2	248.6	82.13	3096	12.45	--
30% off	P2	289.2	101.95	3844	13.29	+6.7
25% off	P2	328.6	104.79	3951	12.02	-3.5
20% off	P2	264.3	93.46	3523	13.33	+7.1
15% off	P2	265.2	104.79	3951	14.90	+19.7
continuous	P3	240.3	73.63	2776	11.55	--
30% off	P3	243.2	96.29	3630	14.93	+29.3
25% off	P3	268.0	93.46	3523	13.15	+13.9
20% off	P3	• 304.1	90.63	3417	11.24	- 2.7
15% off	P3	261.4	82.13	3096	11.84	+ 2.5
continuous	P4	270.7	82.13	3096	11.44	--
30% off	P4	246.2	82.13	3096	12.58	+10.0
25% off	P4	250.3	96.29	3630	14.50	+26.7
20% off	P4	282.7	93.46	3523	12.46	+ 8.9
15% off	P4	294.3	84.96	3203	10.88	- 4.9
continuous	P5	246.8	67.97	2562	10.38	--
30% off	P5	272.5	82.13	3096	11.36	+ 9.4
25% off	P5	252.3	73.63	2776	11.00	+ 6.0
20% off	P5	227.6	73.63	2776	12.20	+17.5
15% off	P5	279.4	79.30	2990	10.70	+ 3.1

* 37.7 MJ/m^3 of natural gas

** percent difference in fuel energy consumption between fan cycled kiln and continuous fan operated kiln

Table 5: Grade composition for priming no. 1 cured in the fan cycled kilns and the continuous fan operated kiln.

Fan	Plant Position (%)		Grade Type (%)					Grade Value
	X	C	O	L	G	CCR	NDX	($/kg)
continuous	50.6	49.4	76.6	--	1.7	--	21.7	3.13
40% off	69.3	30.7	55.9	--	0.5	2.6	41.0	2.70
30% off	72.7	27.3	79.7	--	1.2	1.0	18.2	3.23
20% off	47.6	52.4	78.3	--	0.9	0.7	20.2	3.19
15% off	44.5	55.5	37.5	18.2	33.8	3.5	7.0	3.38

Table 6: Grade composition for priming no. 2 cured in the fan cycled kilns and the continuous fan operated kiln

Fan	Plant Position (%)	Grade Type (%)					Grade Value
	C	O	L	G	CCR	NDC	($/kg)
continuous	100	27.1	40.6	29.6	2.7	--	3.57
30% off	100	51.5	20.0	17.9	1.7	8.9	3.52
25% off	100	--	82.0	7.8	1.7	8.5	3.38
20% off	100	--	73.4	25.1	1.5	--	3.64
15% off	100	65.9	--	19.0	2.5	12.6	3.34

Table 7: Grade composition for priming no. 3 cured in the fan cycled kilns and the continuous fan operated kiln

Fan	Plant Position (%)		Grade Type (%)						Grade Value
	C	H	O	F	L	G	CCR	NDC	($/kg)
continuous	10.5	89.5	62.2	--	--	27.3	0.8	9.7	3.50
30% off	4.7	95.3	62.1	--	--	33.2	1.9	2.8	3.71
25% off	9.2	90.8	3.2	23.4	36.6	27.6	1.1	8.1	3.46
20% off	0.6	99.4	19.5	--	28.7	51.2	0.6	--	3.55
15% off	7.5	92.5	24.4	--	21.9	46.2	2.8	4.7	3.54

Table 8: Grade composition for priming no. 4 cured in the fan cycled kilns and the continuous fan operated kiln.

Fan	Plant Position (%)	Grade Type (%)							Grade Value
	B	M	O	F	G	V	BCR	NDB	($/kg)
continuous	100	--	44.4	17.8	6.4	30.3	1.1	--	3.74
30% off	100	32.7	44.8	--	20.6	--	1.9	--	4.02
25% off	100	20.6	43.1	5.2	29.9	--	1.2	--	3.94
20% off	100	38.7	28.8	--	24.8	--	0.7	6.9	3.77
15% off	100	--	44.3	34.5	15.0	--	0.6	5.6	3.72

Table 9: Grade composition for priming no. 5 cured in the fan cycled kilns and the continuous fan operated kiln.

Fan	Plant Position (%)	Grade Type (%)							Grade Value
	B	M	O	F	G	R	BCR	NDB	($/kg)
continuous	100	16.4	11.8	3.4	67.7	--	0.7	--	3.52
30% off	100	37.0	28.8	--	32.7	0.3	1.2	--	3.53
25% off	100	60.3	31.6	--	6.8	--	1.3	--	3.98
20% off	100	56.6	35.5	--	6.3	--	1.6	--	4.05
15% off	100	15.0	22.6	37.6	11.5	--	1.4	11.9	3.64

Table 10: Chemical analysis of tobacco cured in the fan cycled kilns and the continuous fan operated kiln.

Fan Treatment (% of 30 min.)	Priming	% Total Alkaloids	% Reducing Sugars
continuous	P1	2.08	4.25
40% off	P1	2.66	2.72
30% off	P1	2.35	3.36
20% off	P1	2.18	4.01
15% off	P1	2.45	5.37
continuous	P2	2.79	10.7
30% off	P2	2.64	10.8
25% off	P2	2.65	9.14
20% off	P2	2.73	11.6
15% off	P2	2.52	11.4
continuous	P3	2.64	23.7
30% off	P3	2.64	13.0
25% off	P3	2.71	15.5
20% off	P3	2.90	12.2
15% off	P3	2.47	14.0
continuous	P4	2.96	24.8
30% off	P4	2.76	14.1
25% off	P4	3.14	16.5
20% off	P4	3.14	22.0
15% off	P4	2.86	19.0
continuous	P5	3.21	24.6
30% off	P5	4.03	20.1
25% off	P5	4.25	13.5
20% off	P5	4.18	18.2
15% off	P5	4.39	18.0

Table 11: Moisture content and water removed from cures in the reversed leaf kiln and check kiln.

Treatment	Priming	Moisture Content (w.b.) initial (%)	Moisture Content (w.b.) final (%)	Cased Cured Mass (kg)	Water Removed (kg)
check	P1	--	17.6	61.2	-
reversed leaf	P1	--	16.9	62.6	-
check	P2	79.2	13.3	75.3	248.6
reversed leaf	P2	80.6	15.7	74.8	262.0
check	P3	76.5	16.6	88.5	240.3
reversed leaf	P3	81.9	15.8	74.4	283.5
check	P4	73.7	15.2	113.9	270.7
reversed leaf	P4	72.5	16.6	102.1	224.5
check	P5	72.6	20.1	116.6	246.8
reversed leaf	P5	72.8	20.0	127.9	273.9

Table 12: Summary of curing times for cures in the reversed leaf kiln and the check kiln

Treatment	Priming	Cure Time (h)	Cure Time (h diff)*
check	P1	214.0	--
reversed leaf	P1	186.0	-28.0
check	P2	199.0	--
reversed leaf	P2	195.0	-4.0
check	P3	216.0	--
reversed leaf	P3	211.5	-4.5
check	P4	209.5	--
reversed leaf	P4	209.5	0.0
check	P5	192.0	--
reversed leaf	P5	187.0	-5.0

*difference in cure time between reversed leaf kiln and check kiln

Table 13: Electrical Consumption for cures in the reversed leaf kiln and the check kiln.

Treatment	Priming	Electrical Consumption Per Cure (kWh)	(% diff)*
check	P1	107	--
reversed leaf	P1	93	-13.1
check	P2	99	--
reversed leaf	P2	97	-2.0
check	P3	108	--
reversed leaf	P3	105	-2.8
check	P4	104	--
reversed leaf	P4	104	0.0
check	P5	96	--
reversed	P5	93	-3.1

* percent difference in electrical consumption per cure between reversed leaf kiln and check kiln

Table 14: Fuel energy consumption for cures in the reversed leaf kiln and the check kiln.

Treatment	Priming	Water Removed (kg)	Gas (m^3)	Fuel Energy (MJ)*	Fuel Energy Consumption (MJ/kg water)	(% diff)**
check	P1	--	70.80	2669	--	--
reversed leaf	P1	--	67.97	2562	--	--
check	P2	248.6	82.13	3096	12.45	--
reversed leaf	P2	262.0	90.63	3417	13.04	+4.7
check	P3	240.3	73.63	2776	11.55	--
reversed leaf	P3	283.5	67.97	2562	9.04	-21.7
check	P4	270.7	82.13	3096	11.44	--
reversed leaf	P4	224.5	84.96	3203	14.27	+24.7
check	P5	246.8	67.97	2562	10.38	--
reversed leaf	P5	273.9	82.13	3096	11.30	-8.9

* 37.7 MJ/m^3 of natural gas

** percent difference in fuel energy consumption between reversed leaf kiln and check kiln

Table 15: Grade composition for priming no. 1 cured in the reversed leaf kiln and the check kiln.

Treatment	Plant Position (%)		Grade Type (%)				Grade Value
	X	C	O	G	A	NDX	($/kg)
check	50.6	49.4	176.6	1.7	0.0	21.7	3.13
reversed leaf	82.8	17.2	1.6	30.8	35.2	32.4	2.40

Table 16: Grade composition for priming no. 2 cured in the reversed leaf kiln and the check kiln.

Treatment	Plant Position (%)	Grade Type (%)						Grade Value
	C	O	L	G	A	CCR	NDC	($/kg)
check	100	27.1	40.6	29.6	0.0	2.7	0.0	3.57
reversed leaf	100	0.0	0.0	29.4	57.7	3.6	9.3	3.17

Table 17: Grade composition for priming no. 3 cured in the reversed leaf kiln and the check kiln.

Treatment	Plant Position (%)		Grade Type (%)						Grade Value
	C	H	O	F	L	G	CCR	NDC	($/kg)
check	10.5	89.5	62.2	0.0	0.0	27.3	0.8	9.7	3.50
reversed leaf	4.5	95.5	0.0	30.6	31.6	33.4	0.4	4.0	3.62

Table 18: Grade composition for priming no. 4 cured in the reversed leaf kiln and the check kiln.

Treatment	Plant Position (%)	Grade Type (%)							Grade Value
	B	M	O	F	G	V	BCR	NDB	($/kg)
check	100.0	0.0	44.4	17.8	6.4	30.3	1.1	0.0	3.74
reversed leaf	100.0	37.3	32.7	0.0	15.0	0.0	0.5	14.5	3.63

Table 19: Grade composition for priming no. 5 cured in the reversed leaf kiln and the check kiln.

Treatment	Plant Position (%)	Grade Type %							Grade Value
	B	M	O	F	G	V	BCR	NDB	($/kg)
check	100.0	16.4	11.8	3.4	67.7	0.0	0.7	0.0	3.52
reversed leaf	100.0	0.0	4.2	2.9	65.7	0.9	1.0	25.4	3.07

Table 20: Chemical analysis of tobacco cured in the reversed leaf kiln and the check kiln.

Treatment	Priming	% toal alkaloids	% Reducing Sugars
check	P1	2.08	4.25
reversed leaf	P1	2.48	3.05
check	P2	2.79	10.4
reversed leaf	P2	2.62	11.4
check	P3	2.64	23.7
reversed leaf	P3	2.96	23.7
check	P4	2.96	24.8
reversed leaf	P4	2.61	26.8
check	P5	3.21	24.6
reversed leaf	P5	4.22	23.9

APPENDIX 1

MOISTURE CONTENT DETERMINATION

Oven Method

Application Moisture is measured by drying in a forced-draft or gravity convection oven. In tobacco, moisture determination is complicated by the presence of volatile substances that are driven off at drying temperatures. Cured tobacco cannot be heat dried to a constant weight; therefore, suitable adjustments in drying techniques must be made. All weights are recorded to the nearest mg. (Oven dried samples can be analyzed for minerals; however, they are not suitable for certain chemical analyses such as alkaloids, reducing sugars etc.).

Apparatus Forced-draft or gravity convection oven, analytical balance, aluminum moisture cans (45 - 65 mm dia. and 20 - 45 mm depth).

Procedure

A. Cured tobacco or equivalent

1. Weigh approximately 5 g of cured tobacco (ground to pass 2 mm or finer screen) into a preweighed moisture can and place uncovered in oven.
2. Dry for 3 h at 99.5 ± 0.5°C in a forced-draft oven or for 18 h in a gravity convection oven.
3. Cover moisture can, place in dessicator for at least ½ h and reweigh.
4. Calculate % moisture.

B. Green tissue

1. Weigh 5 g of green tissue into preweighed moisture can and place uncovered into forced-draft oven.
2. Dry for 16 h at 70°C (green tissue such as tobacco stalks and roots will require longer drying intervals). Increase length of drying time until samples have attained near constant weight.

3. Cover moisture can, place into dessicator for ½ h and reweigh.
4. Calculate percent moisture

Reference

Association of Official Analytical Chemists, Official Methods of Analysis. Ed. 11, p. 55. 1970..

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